RECENT STUDIES OF THE HIGH FIELD – LOW ENERGY IONIZATION COOLING CHANNEL

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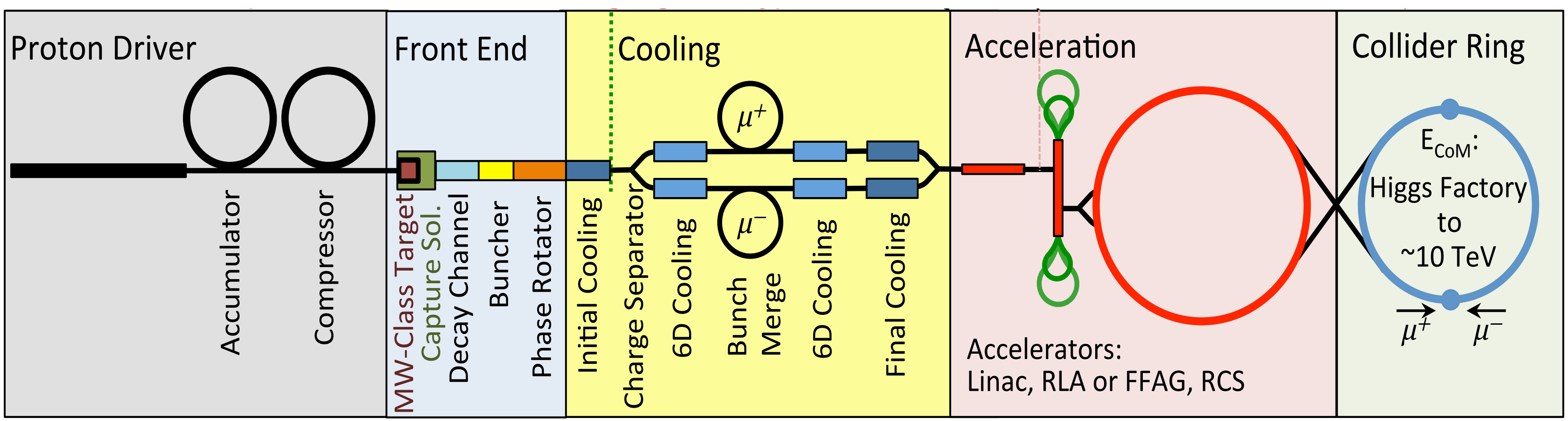
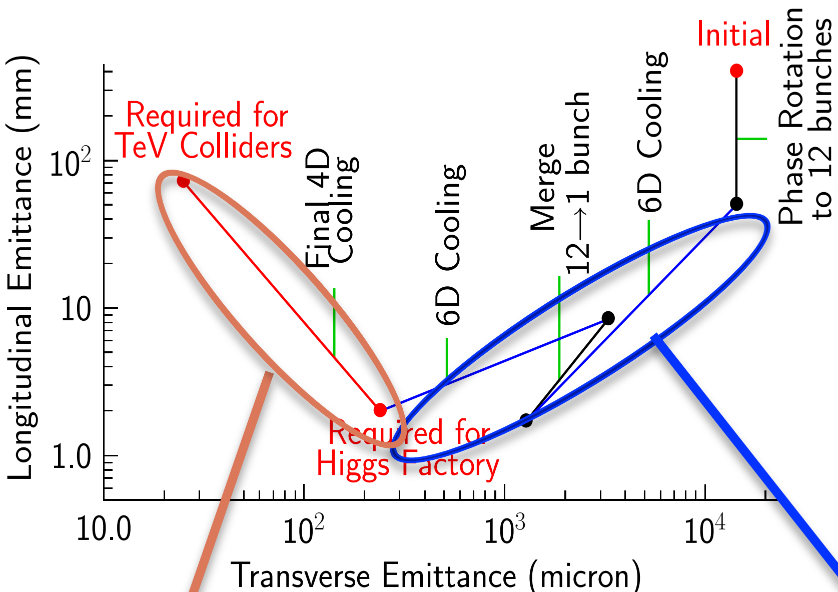
Muon Collider Final Cooling

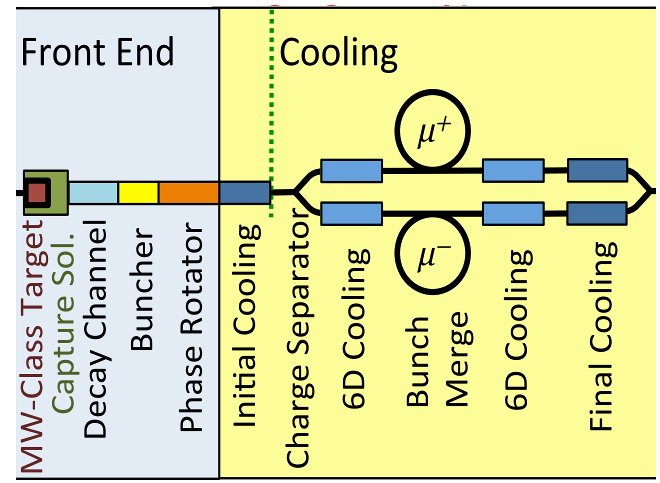
- Muon Collider Ionization Cooling
  - Final Cooling Concept
  - Final Cooling Design & Simulations



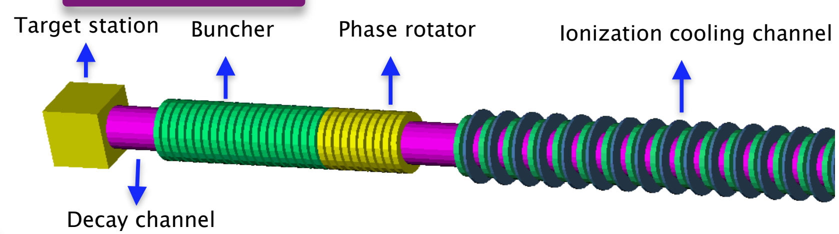
MUON COLLIDER COOLING CONCEPT



R. Palmer *et. al* 2007



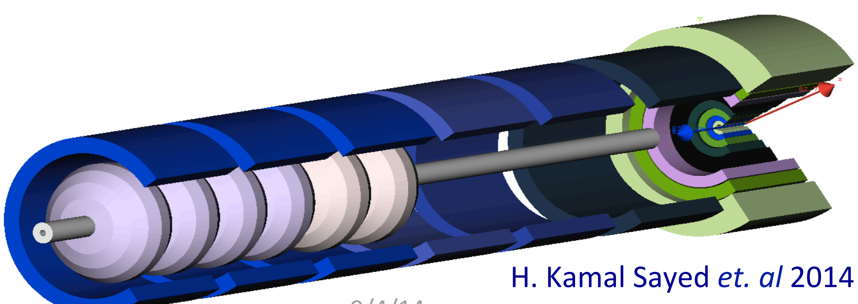
Front End



High field cooling Channel

Target :ε_T= 25 μm ε_L= 72 mm

*** Initially proposed to work at 50 T**

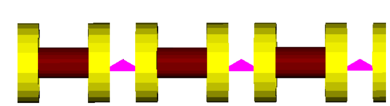


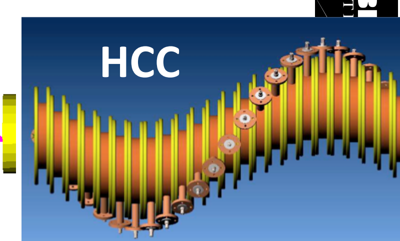
H. Kamal Sayed *et. al* 2014

6D cooling Channels:

Target :ε_T= 300 μm ε_L= 1.5 mm

VCC





MUON COLLIDER COOLING CONCEPT

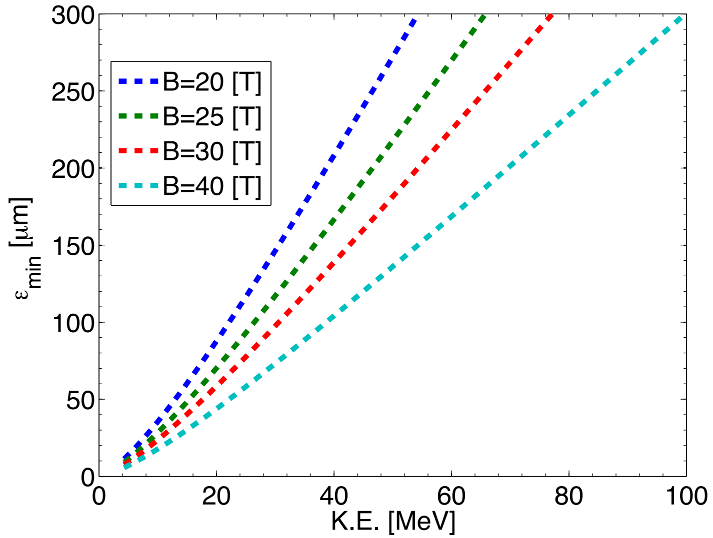
Motivation

- ❑ Muon Collider final cooling requirements → Reduce ε_T from 300 to 50-25 μm-rad
- ❑ Explore the feasibilty of high field – low energy cooling concept

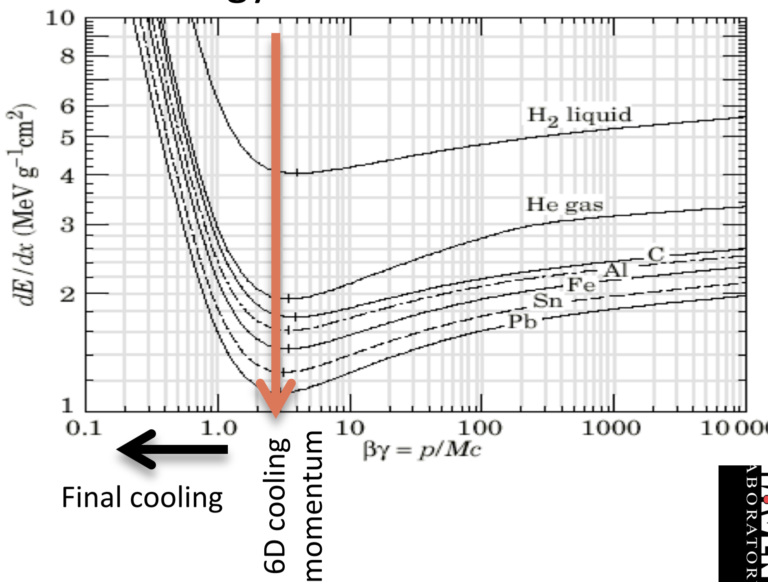
Minimum emittance achievable in a long solenoid field cooling channel

$$\epsilon_{\perp}(min) \propto \frac{E}{B L_R (dE/ds)}$$

B magnetic field
L_R Material radiation length
dE/ds Energy loss in material



Energy loss in low z material



High field – low energy cooling Channel Challenges

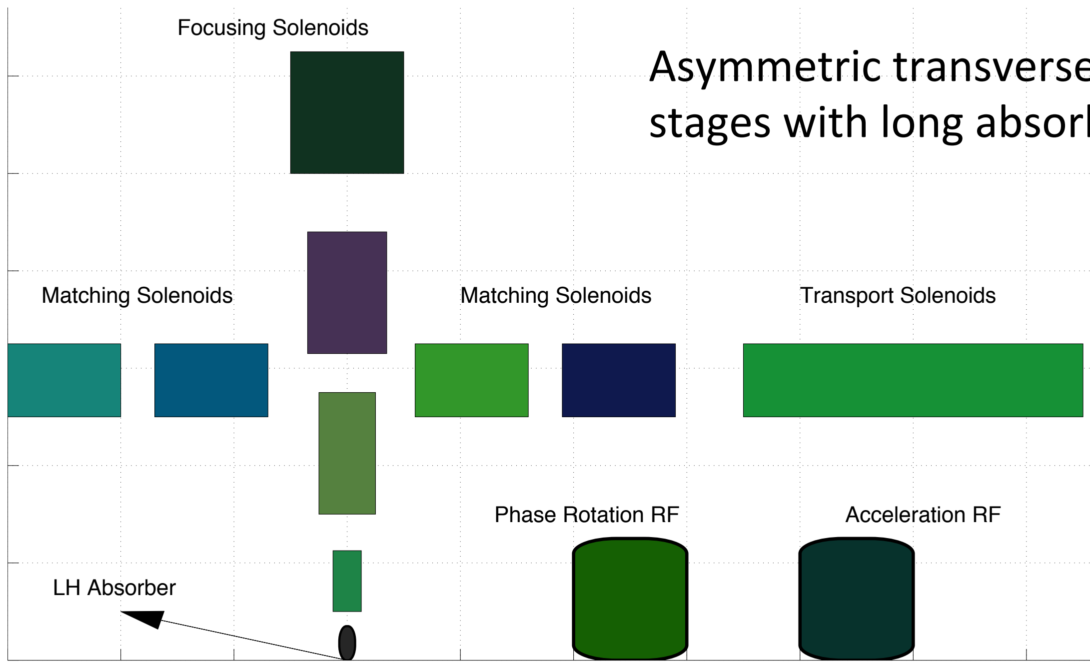
- Requires long absorbers (reduce cost)
- Large energy spread from long absorbers and running on the negative slope of dE/ds curve
  - → Longitudinal and transverse matching
  - → Losses due to low energy tail

HIGH FIELD IONIZATION COOLING CHANNEL DESIGN

Lattice Design & Structure:

16 Stages each stage consists of

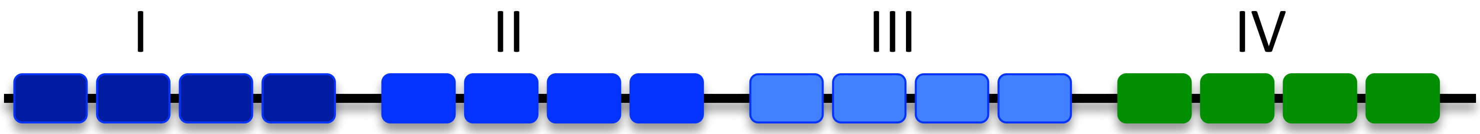
- High field solenoid magnet 25-30 T
- 3.5 T transport solenoid field through the channel
- Asymmetric transverse match to and out of the high field solenoids
- Energy phase rotation to maintain low energy spread
  - → Increases bunch length
  - → Reduce the RF frequencies gradually
- Accelerating RF cavities



Asymmetric transverse match especially in early stages with long absorbers

COOLING SOLENOIDS DESIGN

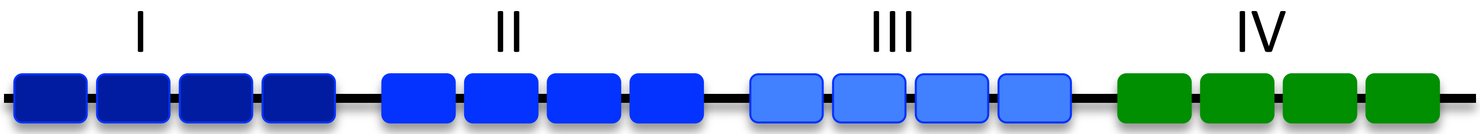
The channel consists of 16 stages divided into four groups
Field profile of each of the groups is optimized



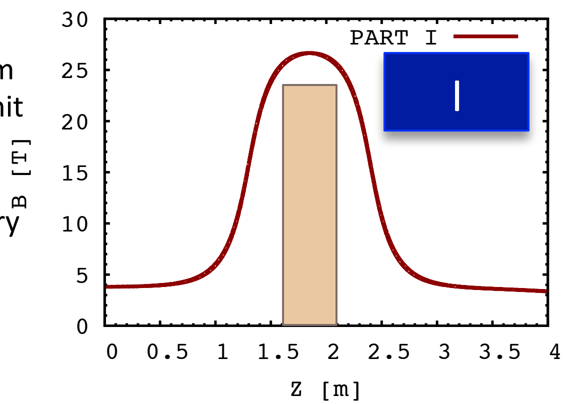
- Drop the momentum of the muon beam gradually
- LH_2 Absorbers thickness reduced gradually
- Energy spread kept within acceptable limits
- Bunch length increases from 5 cm to 1.7 m
- RF frequencies drop from 325 MHz to 20 MHz

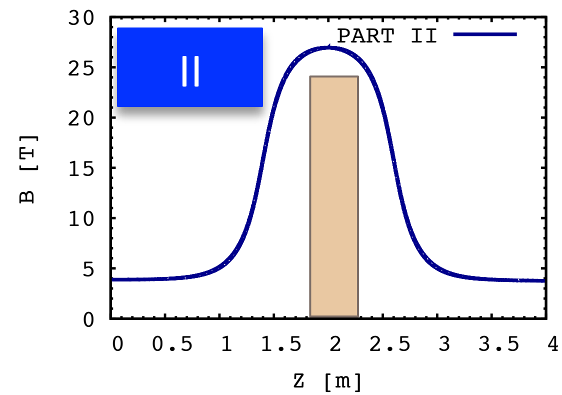
COOLING SOLENOIDS DESIGN

The channel consists of 16 stages divided into four groups
Field profile of each of the groups is optimized



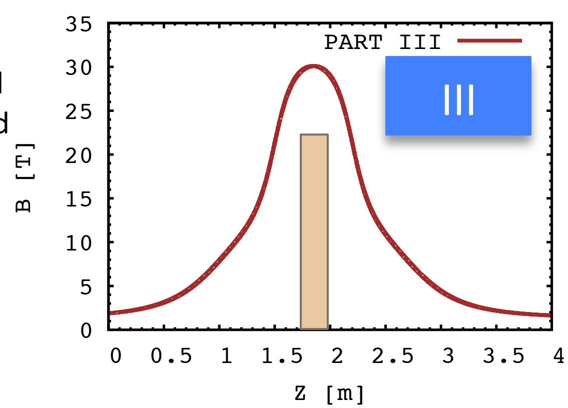
- Long absorbers 65-59 cm
- Limit field integral to limit the transverse – longitudinalcoupling
  → Limit unnecessary increase in σ_t

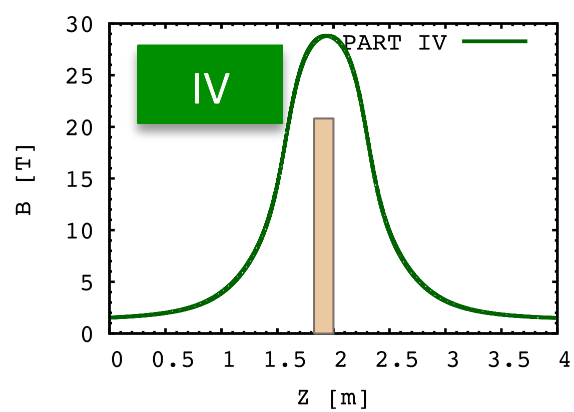




- Long absorbers 57-40 cm
- Relatively smaller transverse amplitudes
  + already longer bunch length

- Medium absorber thickness 35-20 cm
- Larger energy spread will lead to unwanted chromatic effects

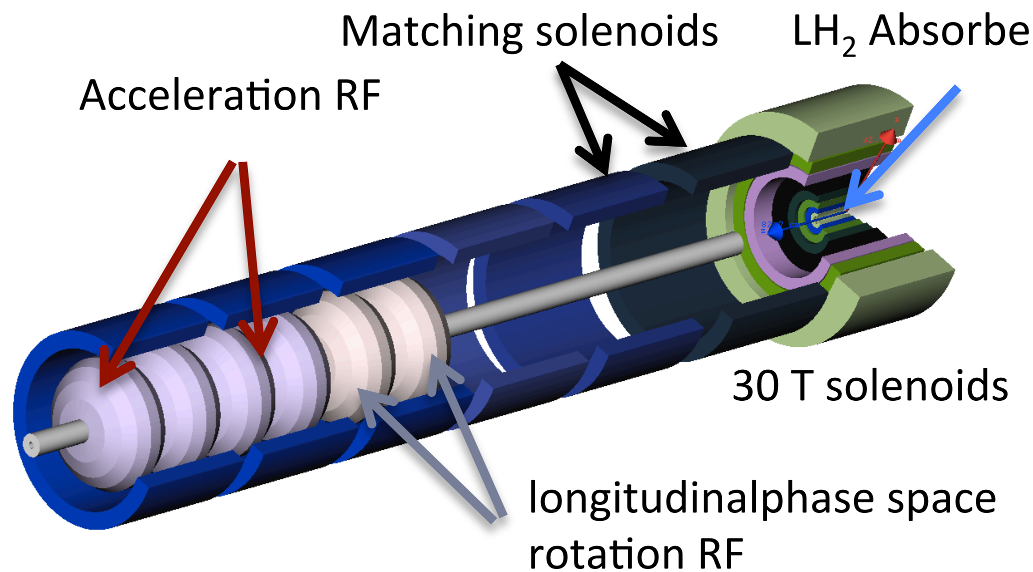




- Small absorber thickness 20-10 cm
- Very small transverse amplitudes

HIGH FIELD IONIZATION COOLING CHANNEL DESIGN

Lattice Design & Structure

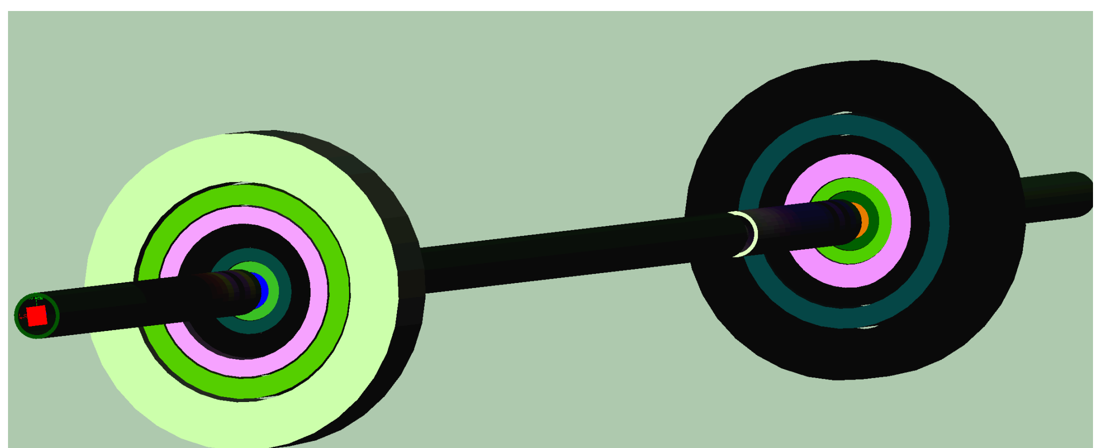


Early Stages

- Short bunchs → High frequency 325 MHz
- RF inside transport solenoid coils

Late Stages

- Long bunch length → Low frequency 20 MHz
- transport solenoid coils inside induction linac



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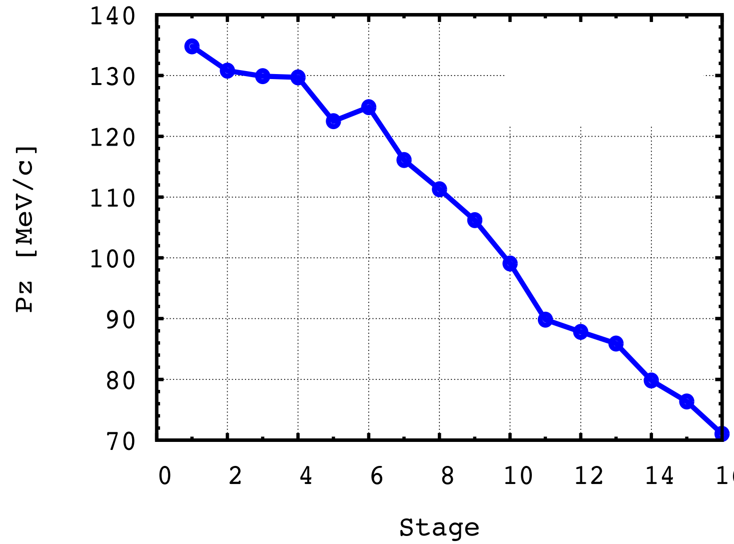
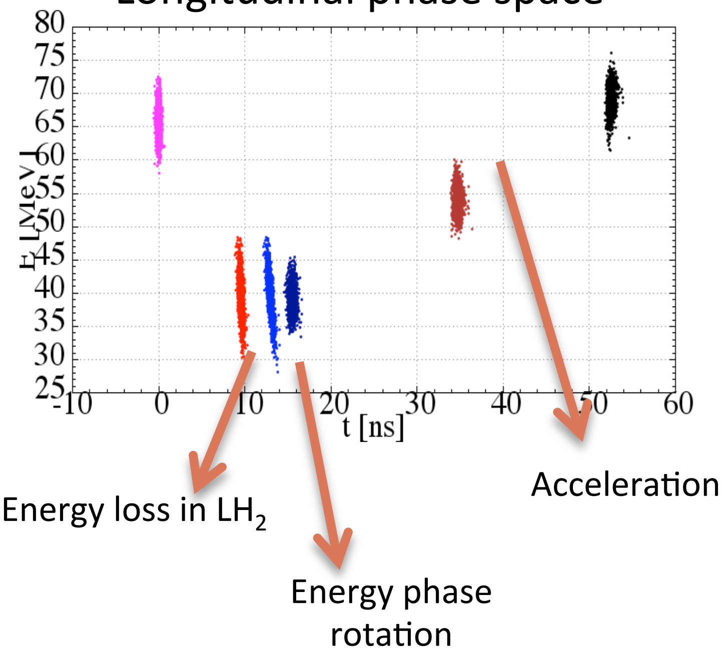
BEAM ENERGY, BUNCH LENGTH, AND LONGITUDNAL PHASE SPACE

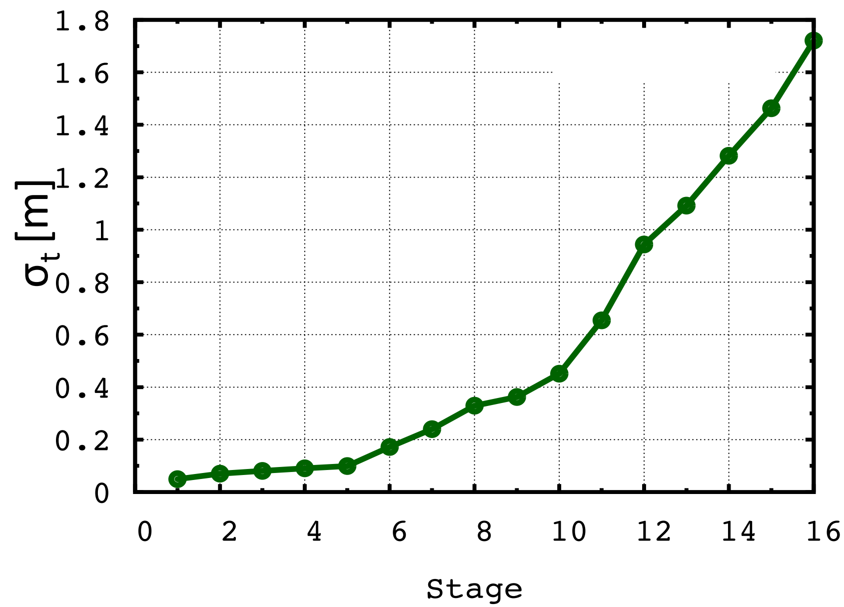
Control of energy spread & bunch length

- Energy spread increases inside LH_2 absorbers
- Energy phase rotation to decrease energy spread on the expense of the bunch length
- optimization of drift length for time-energy correlations which gives the required energy spread for the following stage



Longitudinal phase space

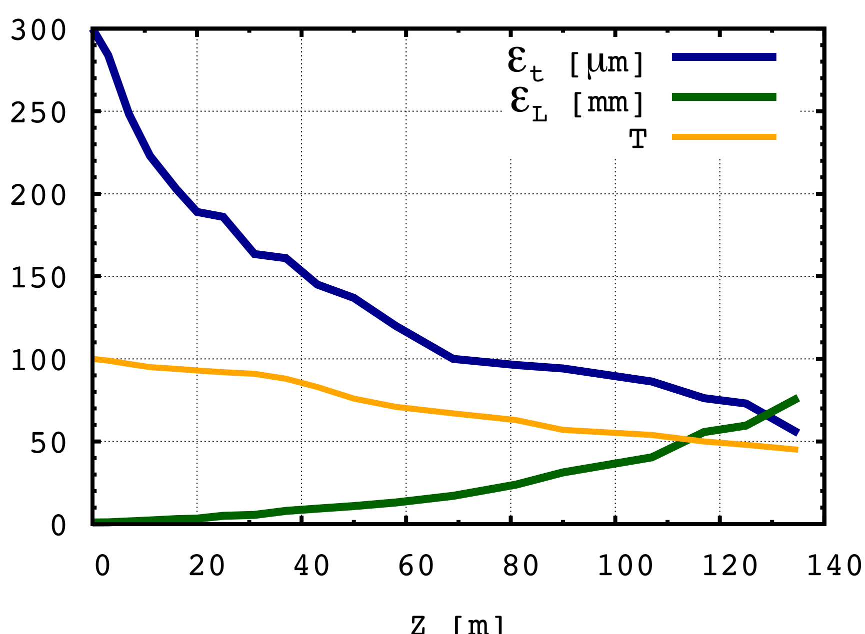




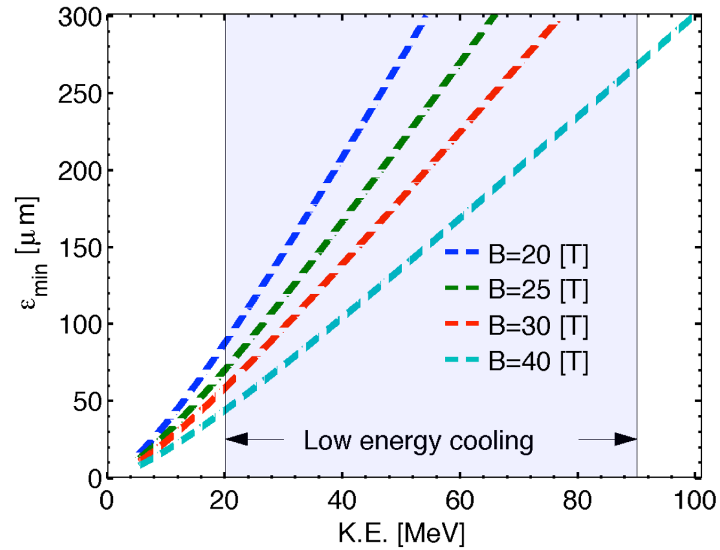
SIMULATION OF 25 – 30 T CHANNEL

The high field - low energy cooling channel G4BEAMLINE simulation:

- The magnetic field of the solenoids was computed by G4BEAMLINE using a realistic configuration of coils and their current settings.
- The RF cavities were modeled as cylindrical pillboxes.
- Initial Gaussian beam with
- ε_T = 300 μm-rad - ε_L = 1.5 mm
- P= 135.0 MeV/c



Limit K.E 20-90 MeV & B to 30 T



First demonstration of high field – low energy cooling concept with start to end complete design and simulation

CONCLUSION & SUMMARY

- Muon collider requires a low emittance to achieve 10^{34} cm^{-2} s^{-1} luminosity
  - Ionization cooling is the only feasible solution for cooling muons

- Concept and dynamics of final cooling of the muon beam in a high field solenoids
- **First demonstration of high field – low energy cooling concept with start to end complete design and simulation working at B < 30 T →** achieving 55 μm